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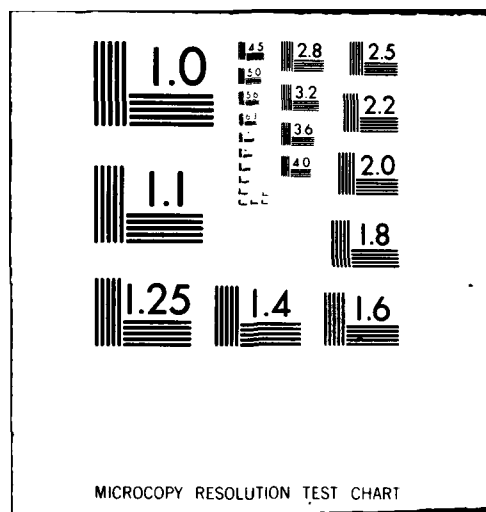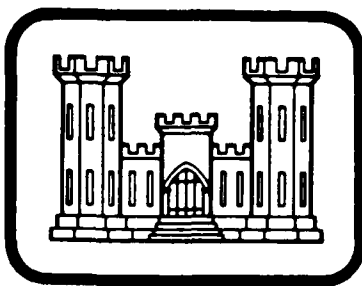
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FACILITIES ENGINEERING SUPPORT AGENCY

REPORT FESA-TS-2080, TASK ORDER 10

LEVEL

PERFORMANCE EVALUATION OF VINYL REPLACEMENT WINDOWS

AD A089222

P. B. SHEPHERD
JOHNS-MANVILLE SALES CORPORATION
RESEARCH & DEVELOPMENT CENTER
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Replacement windows with structural elements composed of polyvinyl chloride compound have been examined to determine their performance and energy conserving potential. Life cycle costing procedures and a mathematical model have been presented for use in comparing different windows. These methods should be carefully followed as it was not possible to generalize on the suitability of any specific type of window. The major factors which influence window selection include installed cost, air infiltration and →over

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maintenance. It was surprising to find that a window's thermal
transmittance coefficient, "U" value, had only a small impact
on the econ&omic evaluation.

SUMMARY

Old windows, leaky windows, single pane windows, and poorly installed windows may contribute to a large amount of energy use in heated buildings. The purpose of this study was to obtain and evaluate information and data on the durability, performance, and economy of vinyl replacement windows.

Vinyl windows are defined as windows whose frame and sash lineal components have been extruded from polyvinyl chloride compounds. A colored weathering surfacing of a second compound, such as acrylic, may be fixed to the exterior of the polyvinyl chloride lineals. A replacement window is generally considered to be a window of "prime" quality but with attached or separate flanges and/or fitting pieces to permit insertion of the window into a variety of openings left by the removal of the original window. A prime window is one constructed for installation in new construction but which may also be used in retrofit and renovation circumstances.

Vinyl windows can be fabricated with a low coefficient of heat transmission, U value, and low air infiltration. The same is true of wood windows. Thermally efficient metal windows are also available, but their U values may not be so low as is achieved with vinyl and wood. The energy conserving potential of various windows may be compared using conventional equations involving U value, air infiltration and degree days. This is explained in Appendix A. Life cycle costing is also explained in Appendix A. Another approach to window thermal analysis may be taken through mathematical modelling. An example of this is given in Appendix B.

It is not possible to make a general statement on which type of window may be the best choice. The most energy efficient window may not always be the most economical choice. Installed price, air infiltration, degree days and required maintenance may vary considerably among windows and geographic locations.

1

Therefore, each circumstance should be carefully
analyzed using the methods provided in this report.

Replacement of existing windows should be
considered only when repairs, caulking, weatherstripping
and a storm window will not correct a badly damaged or
worn out unit. When replacement becomes necessary, the
new window should be a prime window of improved thermal
design. This report provides methods for comparing the
thermal performance of candidate windows. It is,
perhaps, unfortunate that there is no public
specification to guide the purchaser in selecting vinyl
replacement windows. A suggested specification has been
incorporated in this report and may be used as one tool
in selecting among vinyl windows.

TABLE OF CONTENTS

PREFACE

Dr. P. L. Earle, Consultant, provided initial information for the market survey. His valuable experience in curtain wall design and component selection was most helpful.

Mr. F.A. Gill, Senior Research Chemist, was a major contributor in the area of vinyl weathering and longevity based upon his long association with vinyl siding compounding, testing and manufacture.

Mr. R. H. Neisel, Research Associate, provided inputs relating to building codes.

Mr. M. Albers, Research Physicist, was a valuable resource in the areas of mathematical modeling and heat transfer.

Mr. K. Olsen, Senior Financial Analyst, prepared the financial analysis segments of Life Cycle Costing.

Mrs. Rosie Waterbury, Secretary, proved to be of special value to this study. She was in the process of remodeling her house just as this Task Order commenced. Her experiences with manufacturers' representatives and window installers gave us valuable, first-hand exposure to real-world installed prices of several types of replacement windows.

The following persons contributed valuable ideas and information through personal interviews:

Mr. Dale E. Stroud, Product Manager, B.F. Goodrich Chemical Division.

Dr. James W. Summers, R&D Group Leader, B.F. Goodrich Chemical Division.

Mr. Richard J. Kruszynski, Sales Product Engineer, B.F. Goodrich Chemical Division.

4

Mr. W. Todd, Majestic Building Products, Denver,
Colorado.

Mr. R. Durham, Consultant, Durham International.

Mr. C. A. Carstensen of Perma-lite provided
information on foreign-made windows.

INTRODUCTION

Windows and their role in residential energy use
and conservation may be viewed by some as a topic
addressed by contradiction and confusion. There are
sources which advise one to minimize the glazing area in
homes. [1] There are sources which advise one to maximize
the glazing area on south facing walls.[2] There are
sources which suggest optimizing glazing area on east
and west walls.[3] People are confronted repeatedly by
advertisements displaying the relative thermal
conductivities of window construction materials. The
disparity of these numbers is misleading when it comes
to the selection of windows having different frame
materials of construction. Single, double, and triple
glazing are the subject of other articles.[4,5]

The purpose of this report is to survey only one
facet of windows -- vinyl replacement windows. The
general subject of windows in an energy conservation
plan has been reported by others.[6] The scope and
requirements of this assignment were to, "...conduct a
literature and market survey to determine the
availability and capability of vinyl replacement windows
to save energy and the potential cost effectiveness of
these windows for retrofit and renovation in existing
buildings. An evaluation of information will be made
concerning energy savings, cost effectiveness,
installation, operation, maintenance, safety, code
compliance, product longevity, and product warranty
limitations."

"Vinyl replacement windows" is an expression which
must be defined at the outset. "Vinyl" in this context
means that the basic window frame and glass support
members are comprised of extruded shapes of polyvinyl

chloride compound. This thermoplastic compound may be identical or very similar to that used for a number of years in the exterior building product, vinyl siding. The compound consists of a number of ingredients which may include:

> polyvinyl chloride resin
> titanium dioxide pigment
> optional colorants
> ultraviolet absorbing agent
> lubricant
> stabilizer

"Replacement" seems to be not a rigid term of definition. It appears that a "replacement window" may be a prime window unit supplied with integral or accessory flanges, etc., to facilitate installation in a number of different circumstances. In this sense, a prime, wood window in the hands of a reasonably experienced carpenter might also be considered a "replacement window." Any so-called replacement window may also be fit into new construction as a prime window. A survey made by the author at Fort Rucker, Alabama, on November 1, 1979, revealed that all windows requiring replacement are replaced with new, prime, double-hung, wood windows. It was determined that windows at this facility are of standard, so-called "stock," sizes and may be obtained from local lumber sources. Neither special carpentry skills nor unusual fitting techniques are required. Whenever a prime window needs to be replaced because of rot, damage, or other conditions not correctable with caulking, weatherstripping and possibly installation of a storm window, it should be replaced with a new prime unit of thermally improved design and fabrication.[7,8] Identification of suitable thermal design and fabrication, especially in vinyl replacement windows, is one subject addressed by this report.

The history of windows whose frames are profile shapes extruded from polyvinyl chloride compound is not clear. One source attributed the beginnings of this product to Germany.[9] One of the present American window brands, "Trocal," had its start in Germany and the German company, Dynamit Nobel, is reported to supply the "Trocal" window extrusions. It has been reported that

vinyl windows have a 39 percent share of market in Germany. This large market share was believed attributable in part to the fact that wooden windows produced in Germany following World War II were of very poor quality. German vinyl windows appear to be of very rugged construction with metal reinforcing inserts in the vinyl extrusions. The extrusions themselves were reported to have wall thicknesses of 0.115 to 0.170 inches. American vinyl window extrusions, on the other hand, were reported to have wall thicknesses in the range of 0.065 to 0.070 inches.

Vinyl has also been used in at least one Canadian window, Weatherseal, for about twenty years. The principle uses of vinyl in Canadian windows is as a cladding for wood and aluminum and as accessory parts not exposed directly to the weather. The extent of the availability of "all-vinyl" windows in Canada was not determined.

Vinyl windows were first sold in America during the early 1960's. This window was called Koroseal, and it was assembled from extrusions supplied by the B. F. Goodrich Company.

Very few of the firms who market vinyl windows may be classified as integrated manufacturers. Only the following named firms were reported to extrude vinyl window frame profiles, assemble, and market the completed window.

> Fiberlux Corporation
> Poly-Tex Corporation
> Thermall Industries
> Vinyl Building Products
> Certain-teed Products Corporation

It appears that other sources of completed window units are assemblers of window components. The frame extrusions are produced by a small number (probably six) of companies who sell long lengths of window frame profiles, called lineals, to local converters. These converters cut the lineals, insert glazing, and complete the window fabrication. The local converter may also sell and install the completed windows. He may also

sell completed units to home improvement contractors. It was not clear whether the converter or the home improvement contractor solicits builder sales. The manufacture and distribution of vinyl windows seems to hold many parallels with the aluminum storm window business. The existence of a large number of regional and local converters has made it extremely difficult to obtain authenticated, technical and performance data on many specific window brands.

This report consists of the Market Survey, Literature Survey, Specifications for Windows, Performance Considerations, and Criteria for Window Selection. The Appendices contain a means to calculate life-cycle costing and a mathematical model of a window's thermal performance.

MARKET SURVEY

Method

The following actions were taken to secure a broad base of information relative to the manufacture, use, performance, and cost of vinyl replacement windows:

.letter to manufacturers,

.interviews with various sources associated with window industry and replacement window use,

.consultant's attendance at trade shows in Germany and in Chicago.

Letter to Manufacturers

The letter sent to manufacturers is reproduced on the following page. The source of manufacturers solicited was the Thomas Register[10] and all firms listed under the following categories were solicited:

.vinyl windows
.replacement windows
.plastic windows
.storm windows

JM **Johns-Manville**
Sales Corporation

Research & Development Center

Ken-Caryl Ranch
Denver, Colorado 80217
(303) 979-1000

October 23, 1979

Dear Sir:

The Johns-Manville R&D Center has been contacted to
provide a study on the advantages and use of plastic
replacement windows. We would like to receive from you
advertising and technical literature, selling prices and
installation costs for your window units. We are
especially interested in independent testing results of
compliance of your various plastic window units to the
performance and physical standards of the following public
specifications:

    Air infiltration by ASTM E283
    ANSI/NWMA I.S. 2-73
    ANSI/AAMA 302.9, 1977
    ANSI A 134.1
    AAMA Standards of Thermal Performance

We are also interested in mathematical models and life
cycle costing examples of plastic windows in both new and
retrofit circumstances.

Yours truly,

P. B. Shepherd

10

Approximately 300 inquiries were mailed and the pertinent response was very poor. The names of respondents are listed below:

State Metal Awning Inc.
131 Shonnard Street
Syracuse, New York 13209

Trocal Window Systems
Dynamit Nobel of America, Inc.
105 Stonehurst Court
Northvale, New Jersey 07647

Evans Products Co., Inc./Remington Aluminum
100 Andrews Road
Hicksville, New York 11801
(Vinylview Windows)

Vinylume Products, Inc.
134 E. Woodland Ave.
Youngstown, Ohio 44502
(Vinylume Windows)

A great many replies were received from manufacturers of specialty plastic windows which had no application to the exterior walls of buildings. Additional manufacturers' literature was obtained through the good offices of consultants, from home improvement contractors, and at trade shows. These manufacturers were:

Poly Company of America, Inc.
Highway 5
East Langdon, South Dakota 58249

Rusco Industries Inc.
RD#2, Box 124
Cochranton, Pennsylvania 16314

Vinyl Sash, Inc.
3707 W. 73rd Ave.
Westminster, Colorado 80030

ThermoFrame by
the Mintz Company
(no address on literature)

Certain-Teed Products Corp.
Valley Forge, Pennsylvania

Dura/Frame Windows
Durham Manufacturing, Inc.
6950 N. W. 12th Ave.
Ft. Lauderdale, Florida 33309
(These windows are no longer available.)

The information obtained from manufacturers'
literature is used throughout this report. This
information was of limited help in addressing the goals
and objectives of the assignment, because of
inconsistancies in the nature of technical data supplied
by the window companies.

A number of window manufacturers who do not produce
polyvinyl chloride replacement windows volunteered
literature on their products. These windows fell into a
category which might be described as either hybrid or
composite. For example, these windows included aluminum
or vinyl cladding on wood, and frames structurally
composed of two materials such as vinyl and aluminum.
These windows may present promising alternatives where
thermal efficiency, low maintenance and long-proved
structural components are desired attributes. The
respondents in this category are listed below.

Rolscreen Company
Pella, Iowa 50219
(Aluminum clad wood)

Winterseal of Flint, Incorporated
209 Elm Street
Holly, Michigan 48442
(Aluminum outside, vinyl inside)

Alcoa Building Products Incorporated
2 Allegheny Center
Pittsburgh, Pennsylvania 15212
(Aluminum and vinyl, weatherside varies)

Weather Shield Manufacturing Incorporated
PO Box 309
Medford, Wisconsin 54451
(Aluminum clad wood, vinyl clad wood)

Anderson Corporation
Bayport, Minnesota 55003
(Vinyl clad wood)

This cross section of window constructions provided a good representation for the various types in the market place. A complete list of the different window construction materials appears below:

Wood
PVC clad wood
Aluminum clad wood
Aluminum
Aluminum with thermal break
PVC-clad aluminum
Extruded PVC
Metal reinforced PVC
Steel
Foamed polystyrene
PVC clad CPVC
PVC and aluminum

Physical and performance properties claimed by those manufacturers who responded are tabulated in Tables 1 and 2 on the following pages. Each reported value is footnoted to indicate the source of the test method used. Occasional failure to disclose the test methods made it difficult to compare the various window units. Another potential area of confusion lies in comparison of "U" values. ASTM C-236 is the only accepted, public test method for this attribute. Some laboratories can test windows with a single dimension up to five feet. Many others are limited to smaller sizes. Window "U" values should be reported for the actual size tested. Thermal performance of other size windows may

not be precisely extrapolated from area or perimeter comparisons. The "U" values of other window sizes may be estimated using the mathematical model in Appendix B. Such a procedure for estimating window thermal performance is, at best, useful for approximate comparisons. Small differences in "U" values between different windows should not be viewed as significant.

The Architectural Aluminum Manufacturers Association has a test method for "Condensation Resistance Factor" which has been claimed to be of value in comparing one facet of apparent thermal performance among windows. This method has not been adopted by ASTM or ANSI.

TABLE 1

REPORTED PROPERTIES OF VINYL WINDOWS

Manufacturer	Trocal	Polyco	Vinyl-lume 500	Evans Vinylview	State Metal Awning "Finesse"	Certain-Teed
Style	Casement	Various	Dbl Hung		Dbl Hung	?
Air Infiltration, cfm/ft	0.01^a	d	0.29^a	$0.59\text{btu}/\text{in}^c$	---	---
Water Penetration, no leak at psf						
Cyclic	15^a	d	2.86^a	---	---	---
Static	15^a	d	4.00^a	---	---	---
Uniform Load Deflection, in.	0.038^a	d	0.198^a	---	---	---
Uniform Load Structural						
Exterior, psf	40^a	d	40^a	---	---	---
Interior, psf	20^a	d	20^a	---	---	---
Permanent Deformation, in.	0.024^a	d	---	---	---	---
Horizontal Deflection, in.	0.020^a	d	0.200^a	---	---	---
Wind Load						
Exterior, psf	91^a	d	---	---	---	---
Interior, psf	52^a	d	---	---	---	---
Permanent Deformation, in.	0.035^a	d	---	---	---	---
U Value	---	0.37^c	---	0.61^c	0.52^c	0.65^c
Condensation Resistance Factor	74	---	---	50^c	58^c	55^c

[a] ANSI A134.1-1972   [c] Method not reported

[b] Calculated, not tested   [d] Claim to exceed NWMA requirements

TABLE 2

REPORTED PROPERTIES OF COMPOSITE WINDOWS

Manufacturer	Weather Shield	Alcoa	Season All	Andersen
Style	All	Various	---	"Typical"
Air Infiltration, cfm/ft	0.09-0.17[f]	---	---	0.25[b]
Water Penetration, no leak at psf				
Cyclic	e	---	---	
Static	e	---	---	
Uniform Load Structural				
Exterior, psf	e	30-55?[g]	---	
Interior, psf	e	30-55?[g]	---	
Permanent Deformation, in.	e	---	---	
Horizontal Deflection, in.		---	---	
Wind Load				
Exterior, psf	e	---	---	
Interior, psf	e	---	---	
Permanent Deformation, in.	e	---	---	
U Value	---	0.60-0.68[g]	---	0.52[b]
Condensation Resistance Factor	---	51-55[g]	---	

---

[a] ANSI A134.1-1972

[b] Calculated, not tested

[c] Method not reported

[d] Claim to exceed NWMA requirements

[e] Claim to comply with ANSI 134.1 or 134.2

[f] AWMA I.S. 2-(yr)

[g] AAMA 1502.6

Interviews

Personal interviews were held with a number of persons in an effort to describe the composition and market channels of the vinyl replacement window business. Information was also sought concerning performance experience, life expectancy, test data of other than manufacturers' claims, and cost effectiveness. Persons who graciously agreed to supply information were:

Mr. Robert Durham, Consultant and President of
Durham International
Fort Lauderdale, Florida

B.F. Goodrich Chemical Company
Cleveland and Avon Lake, Ohio

    Mr. Dale E. Stroud, Product Manager
    Mr. Richard J. Krusznski, Sales Product
        Engineer
    Dr. James W. Summers, R&D Group Leader

Dr. P. L. Earle, Consultant
Denver, Colorado

Mr. F. Gill, Senior Research Chemist
Johns-Manville Research & Development Center
Denver, Colorado

Mrs. Rosie Waterbury
Johns-Manville,
Denver, Colorado

Mrs. Waterbury was considering replacing the windows in her home just as this study commenced. Her brother had purchased an installation of replacement vinyl windows several months prior. Their practical and real-life interface with the process of choosing and purchasing replacement windows added a valuable dimension to this study.

Mr. Durham was a pioneer in the extrusion of profiles for the frames of vinyl windows. He was identified early-on as an outstanding, world-wide

consultant in this field. His willingness to cooperate
in this study was outstanding and the quality of
information provided was excellent.

The B. F. Goodrich Company is a major manufacturer
of polyvinyl chloride resin and extrusion compound used
in vinyl building products such as windows and siding.

Dr. P. L. Earle is an energy consultant who has
assisted Johns-Manville in several studies relating to
energy conservation products and methods.

Mr. F. Gill was the principle technical
professional assigned to Johns-Manville's vinyl siding
business several years ago. His experience with vinyl
building products, data on the weatherability of vinyl
compounds, and industry contacts were of great help.

Interviews with window manufacturers were
considered as a response to the letter survey and are
not separately cataloged here. All of the information
obtained through interviews was cataloged according to
the subjects referenced in the index. This information
was then integrated into the overall presentation. It
is not within the scope of this report to separately
summarize each interview.

LITERATURE SURVEY

The literature survey was conducted by
Ms. Suzanne D. A. Graham who is on the Corporate
Information Center staff at the Johns-Manville Reserach
& Development Center. Computer sources were used
extensively. The primary and most productive sources
for reference materials were:

NTIS-National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia

Compendex Engineering Index Inc.
New York, New York

Energyline Environment Information Center, Inc.
New York, New York

Ismec Data Courier, Inc.
Louisville, Kentucky

One hundred forty-seven citations were disclosed in
the search. Nearly two dozen of these were selected
based on the brief synopsis supplied for each citation
and these were obtained from appropriate sources. Very
little was disclosed relating specifically to vinyl
replacement windows. Much valuable information was
obtained relating to the quality, performance, design
and selection of windows in general. That information
pertinent to the objectives of this study has been
incorporated in this report, footnoted, and listed in
the Reference Section. All literature citations which
were found as relating to windows have been incorporated
in the Bibliography.

SPECIFICATIONS

There are a number of public specifications and
standards relating to windows. These were generally
written by industry associations and are intended to be
applied to a specific type of window, i.e., wood, steel
or aluminum. The technical and market surveys disclosed
no industry standards or public specifications written
for vinyl (replacement) windows in the United States.
Canadian CSA Standard A274 references vinyl windows.
However, the document appears to be more applicable to
vinyl clad windows having wood or metal structural
cores.

Following is a list of specifications, standards
and codes applicable to windows. Each is discussed in
detail and, finally, physical and performance guidelines
are recommended for use in selecting vinyl windows or in
comparing them to alternative choices.

ASTM E283 Standard Test Method for Rate of Air
Leakage Through Windows, Curtain Walls and Doors.

19

ASTM E330 Standard Test Method for Structural
Performance of Exterior Windows, Curtain Walls and
Doors Under the Influence of Wind Loads.

ASTM E547 Standard Test Method for Water
Penetration of Exterior Windows, Curtain Walls and
Doors by Cyclic Static Air Pressure Differential.

ASTM E331 Standard Test Method for Water
Penetration of Exterior Windows, Curtain Walls and
Doors by Uniform Static Air Pressure Difference.

ASTM E405 Standard Methods of Wear Testing Rotary
Operators for Windows.

ASTM E163 Standard Methods of Fire Tests of Window
Assemblies.

ANSI/NWMA I.S. 2-73 Wood Windows

ANSI/AAMA 302.9 Specifications for Aluminum Windows

ANSI A134.1 Specifications for Aluminum Windows

AAMA 1502.6 Voluntary Standards and Tests of
Thermal Performance of Residential Insulating
Windows and Sliding Glass Doors.

Code for Energy Conservation in New Building
Construction, December 1977 jointly prepared by
BOCA, ICBO, NCSBCS, and SBCCI.

BOCA Basic Building Code, 1979.

Uniform Building Code, 1979 Edition.

Standard Building Code, 1979 Edition.

One and Two Family Dwelling Code, 1975, jointly
prepared by BOCA, ICBO, NCSBCS and SBCCI.

ASTM E-283 is a frequently referenced method for
testing the air leakage of windows. The test method
does not specify the pressure drop to apply across the

window. A pressure of 1.567 foot pounds per square foot is referenced in the Energy Conservation Code and a maximum air leakage of 0.5 cfm per foot of operable sash crack is specified. The pressure of 1.567 foot pounds per square foot is considered to approximate the effect of a 25 mph wind. The equipment used to perform the E-283 test may also be used in E-330, E-331 and E-547 which are described in the following paragraphs. The equipment used in these tests is basically a wall section containing an apperature to receive a test window. The wall section is affixed to an air chamber which contains calibrated water sprays. The chamber is provided with means for controlled pressurization and evacuation. Suitable pressure and volume measuring devices are specified.

ASTM E-330 is a test for the structural performance of windows under wind loads. There are two different procedures contained in this method. Procedure A describes a regimen of preselected loading and deflection measurement. Procedure B requires loading the window to failure as well as recording deflection measurements.

ASTM E-547 and ASTM E-331 are tests for measuring the resistance of a window to penetration by rain under prescribed conditions of pressure and water flow. E-547 is a cyclic test designed to create a sort of pumping action whereas E-331 uses static pressure.

ASTM E-405 is a test designed to evaluate the durability of rotating hardware used on casement type windows.

ASTM E-163 is a rather severe fire test incorporating a resistance to a hose stream. It appears to be a very severe test for residential windows.

There are no public standards for vinyl windows in America and, therefore, no guidelines for judging a window's acceptability based on its performance in the various tests. There are voluntary standards for wood windows, ANSI/NWMA 2-73, and for aluminum windows,

ANSI/AAMA 302.9 and ANSI 134.1. Some manufacturers of vinyl windows have referenced these standards in their literature.

For example:

Trocal has offered test data showing the performance of their window against ANSI A134.1; yet the unit tested was smaller than specified in the standard.

Fiberlux claimed in 1977 compliance with ANSI 302.9, yet the unit tested failed in uniform load deflection and both horizontal and vertical load, unglazed.

Rusco has claimed A134.1 compliance yet cautions, "don't support unit by corner".

Building codes have had no requirements pertinent to residential replacement and prime windows until the four major code groups published jointly, the Code for Energy Conservation in New Building Construction. This code does specify an air leakage limit, 0.5 cfm per foot of sash crack at 1.567 pounds per square foot. It also references the use of window "U" value but does not specify a maximum limit for "U" value.

The absence of voluntary standards and public specifications for vinyl windows makes it difficult to offer definitive guidelines for the selection and purchase of such units. The following specification is offered as a suggestion based upon accepted values for other building materials and windows. It is hoped that the window industry and ANSI may soon publish a specification for consumer guidance.

Suggested Specifications for Vinyl Replacement Windows

1. Frame and lineals construction material.

The compounds from which the window parts are extruded shall meet the following requirements.

1.1. All polyvinyl chloride components used to fabricate --- windows have been extruded from polyvinyl chloride compounds expressly formulated for exterior exposure and use. The outdoor color stability and impact strength retention of this compound has been tested for at least two years by --- at ---.

1.2. All polyvinyl chloride components used to fabricate --- windows shall comply with NBS Voluntary Product Standard PS 55-72, paragraph 3.10.

1.3. All polyvinyl chloride components. used to fabricate --- windows shall comply with ASTM D-1784 Class ----- - The compound is to be designated by a series of five numbers and a letter suffix chosen as follows.

(First Number)	1
(Second Number)	2, 3, 4, 5 or 6
(Third Number)	3, 4, 5, or 6
(Fourth Number)	4, 5, or 6
(Fifth Number)	4, 5, or 6
(Suffix)	C

Note: Typical compound classes are:

12454 - C
13454 - C
13447 - C

1.4. All chlorinated polyvinyl chloride components

used to fabricate --- windows shall comply
with ASTM D-1784 - Class -----.

(First Number)	2
(Second Number)	2, 3, 4, 5, or 6
(Third Number)	3, 4, 5, or 6
(Fourth Number)	4, 5, or 6
(Fifth Number)	5, 6, 7, or 8

1.5. Components of white and pastel colored windows shall be composed of polyvinyl chloride.

1.6. Components of dark colored windows shall be composed of chlorinated polyvinyl chloride co-extruded with a cap stock of weatherable polyvinyl chloride.

2. Glazing.

Glazing panels shall be composed of glass of a type and thickness agreed upon between purchaser and seller. The glazing panels must comply with local building codes whenever applicable. A minimum of two parallel glazing panels (dual glazing) shall be provided.

3. Hardware.

All hardware supplied as a part of the window shall comply with the appropriate "hardware" section of ANSI Specification A134.1.

4. Physical and Performance Properties.

4.1. Air Infiltration.

Air infiltration for all types and sizes of
windows shall be 0.5 cfm per foot of operable
sash crack, maximum. Testing shall be in
accordance with ASTM E283 with a pressure of
1.567 foot pounds per square foot.

4.2. Thermal Conductance.

The coefficient of heat transmission, U value,
of all windows having a nominal size of
15 square feet or larger shall not exceed
0.60 BTU/sq ft/$^\circ$F/hr. Windows of smaller size
shall not exceed 0.50 BTU/sq ft/$^\circ$F/hr. Testing
shall be in accordance with ASTM C-236 at a
mean temperature of 70°F.

4.3. Other properties.

Additional physical and performance properties
of vinyl windows shall be in accordance with
ANSI Specification 134.1 for each of the
following types.

DH-B1-HP	Double hung (also single hung)
C-B1-HP	Casement
P-B1-HP	Projected
A-B1-HP	Awning
HS-B1-HP	Horizontal sliding
J-B1-HP	Jalousie
VS-B1-HP	Vertical sliding

CONSIDERATIONS APPLICABLE TO REPLACEMENT WINDOW
SELECTION

A great deal has been written about energy criteria
applicable to the size, location and installation of
prime windows. This was briefly discussed in the
Introduction. Most of these considerations do not apply
to the selection of replacement windows. Other
considerations such as window management with drapes and
shades are also not within the scope of this Task Order.
There remain, however, a large number of factors to be
considered when making a decision whether or not to

replace a window and in deciding among the various
alternatives of window types and sources. The factors
to be considered which are discussed as topics within
this section include:

Should a Window Be Replaced?

Selection Factors For Vinyl Replacement Windows -

•energy conservation
•cost effectiveness
•installation
•operation
•maintenance
•safety
•building codes
•product life (durability)
•product warranty
•rain penetration

Should a Window Be Replaced?

It has been previously mentioned that a window should be
replaced only when conditions such as rot, damage or
structural movement are not correctable with caulking,
weatherstripping, or, possibly, storm windows.[11] When
replacement becomes necessary, only prime windows of
thermally improved design and construction should be
used.[12] Any experienced carpenter or Facilities Chief of
Buildings may determine, by inspection, if a window
should be replaced.

Selection of Vinyl Replacement Windows.

The following sub topics represent the factors to be
considered when selecting a new window unit to replace
one which is not repairable. The discussion is aimed at
vinyl windows, but the considerations may be applied to
many other types of windows. Specific selection
criteria derived from the following factors are
presented in the next section of this report.

Energy Conservation

Two measurable qualities of a window relate

directly to its role in energy conservation. The first
quality is "U" value, which is a measure of the window's
thermal conductance. The lower the "U" value of the
total window, the better will be the thermal performance
of the window. The second measurable quality is air
infiltration. The lower the value, the better will be
the thermal performance of the window. It is important
to note that the benefit of a good, thermally efficient
window can be negated by poor or improper installation.

Advertisements for vinyl windows sometimes stress
the relative "U" values of the frame materials thus
making vinyl windows seem to appear far superior to
metal frame windows. This sort of presentation tends to
be misleading when related to total window thermal
performance. The frame material may represent only a
small portion of the total window area and this frame
material is significant only to conductive heat
losses.[13,14] This relative insignificance of frame
material was borne out by detailed laboratory testing
which showed that heat flow associated with leakage was
much larger than that due to thermal conduction in many
of the walls tested.[15] Another source confirmed that
conduction through wood window frames is negligible
compared to the glass area but that for metal frame
windows, the conductance per square inch of frame is
about equal to that per square inch of double
glazing.[16] Since the area of framing is so small,
relative to the area of the glass, the framing material
may have little impact on the total thermal performance
of the window.

Air infiltration is an important characteristic.
Most modern windows from major manufacturers are tested
for compliance with public standards for air
infiltration. As was pointed out in the Sabine
study,[17] air leakage can be a much more significant
factor than conduction in the overall thermal
performance of a window. It is perhaps unfortunate that
leakage tests are made at standard room temperature
conditions. The relative coefficients of thermal
expansion for vinyl and metal suggest that windows made
from these frame materials may leak air to a somewhat
greater extent at lower temperatures than would be
suggested by laboratory test results obtained at room

temperature. The following list of expansion coefficients illustrates a comparison of three frame materials.

Wood	25×10^{-7} in/in/°F
Aluminum	130×10^{-7} in/in/°F
PVC	300×10^{-7} in/in/°F

Consider as an example, a three foot lineal made from each of the above materials. The window is made and installed at 70°F. When the temperature drops to 0°F the length of the three foot piece for each of the frame materials will be:

Wood	35.994 inch
Aluminum	35.967 inch
PVC	35.924 inch

This suggests that crack widths contributing to air infiltration test results at room temperature may widen by up to the following amounts at 0°F.

Wood	0.006 inch
Aluminum	0.033 inch
PVC	0.076 inch.

Air infiltration testing of windows at low temperatures might be a worthwhile subject for laboratory studies. It seems that there is not a major difference between the materials. However, low temperature air infiltration testing using ASTM E-253 is suggested because a window is a three dimensional system whose shrinkage performance may not be accurately represented by simple, linear models.

Window selection for thermal performance should be heavily influenced by available air infiltration test results. Air infiltration and thermal conductance have been included in the procedures for selecting among window alternatives.

It is critical to note that poor or improper installation may negate the anticipated benefits of a thermally efficient replacement window. One field study disclosed that the majority of leakage occurred <u>around</u>

the window frame, between the frame and the wall, and
that proper caulking reduced the measured leakage by 60
percent.[18]

An important factor relative to window thermal
performance is glazing. Double glazing is regarded as
essential and triple glazing can be of value in very
cold climates. The analytical methods of selection
provided in this report will aid in selecting the proper
glazing, provided the manufacturer will disclose
measured "U" values for each of the window units being
considered. Note that we have concerned ourselves only
with heating circumstances. This is because the
National Bureau of Standards has reported that improving
window thermal performance by adding storm windows was
of value only during the heating season.[19]

Window size has not been considered in this study.
The need for replacement presents an opportunity to
consider installing larger windows on south walls in
heating climates and smaller windows on north walls.
However, the impact of window size on building energy
use is not within the scope of this study on vinyl
replacement windows. It is, however, pointed out for
future consideration that changing window sizes
according to exposure direction may have a sizeable
impact on energy conservation.

Cost Effectiveness

The following factors should be considered when
calculating cost effectiveness of windows and comparing
life-cycle costs of windows.

Energy efficiency or BTU per year heat loss
attributable to the window.

Required maintenance such as painting, glazing,
replacement of balance, lock and other hardware.

Initial installed cost.

Life expectancy to required replacement.

The expected life of a window may be a critical

factor in calculating cost effectiveness. A difference of ten years in assumed life may have a major impact on cost comparisons; yet, little has been published about the life expectancy cf the American residential window.

Let us assume that a window will be replaced only when it has been judged tc be non-repairable; for example. the sash has warped out of the frame. There are certainly wood windows which have lasted over 100 years. Yet vinyl windows have been used in America for less than 20 years. It would be unfair to make a life-cycle cost comparison using 100 years for wood and only 20 years for vinyl windows. Department of Energy methods of life-cycle costing as explained in the Federal Register resolve this apparent dilema because they call for a "study period" of 20 years.[20] Where life cycle costing has been mandated, a window life of 20 years is recommended for all windows. Even 20 year extrapolation of investment, energy cost escalation, and carpenter wage rates is viewed as an uncertainty and, perhaps, useful only for comparative purposes.

Installation

There is really only one factor to consider in the installation of replacement prime windows - cost. Considersations of window removal, framing preparation, insertion, fitting and final trim will all be reflected in the installation cost. When window replacement is to be done by outside contractors, it is only necessary to obtain competitive bids on the various window units being considered. When windows are to be replaced using in-house carpenters, there are usually two possibilities.

1. Use any type of window meeting the selection criteria when the window to be replaced is of a contemporary stock size.

2. Use a so-called replacement window when the window to be replaced is not of a contemporary stock size. The accessory fins and expanders of replacement windows should make framing changes unnecessary.

It is interesting to note that ASTM Committee E06 approved late in 1979 installation practices under the Standard entitled, "Proposed Standard Practice for the Installation of Storm Windows, Replacement Windows, Multi-Glazing, Storm Doors and Replacement Doors". Society adoption of the Standard is anticipated during 1980.

Operation

The operation of windows is influenced by window design, hardware, fabrication, and proper installation. ANSI Specification A134.1 calls out an operating force for windows. This may be a useful guideline. Experience and first-hand inspection may provide equally useful guidelines.

Maintenance

Vinyl windows are claimed by many to require no maintenance. This is, of course, not true as any window may require replacement of broken glazing, adjustment or replacement of hardware, and cleaning. Since these may apply equally to all windows, they are ignored when comparing the one maintenance requirement which differs among windows - painting and puttying. The anticipated painting frequency for the various types of windows within the 20 year life-cycle analysis period is shown below for various window frame materials.

Wood -   6 years outside

                                                     7 years inside

Vinyl Clad Wood

  White and pastel -   None outside
                                                     7 years inside

  Dark colors -   Unknown

Aluminum clad wood
  factory painted -   10 years outside
                                                     7 years inside

Aluminum

  Mill finish -   None
  Anodized -   None
  Factory Painted -   10 years

Solid Vinyl -   None

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CPVC with vinyl
   capstock, dark color -              Unknown
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It must be understood that these are estimates offered for use in comparative analysis. It was not within the scope of this study to fine-tune repainting estimates according to climate, exposure and paint quality differences.

Safety

There are no safety requirements relating to residential prime windows in the major building codes. The principle practical consideration relates to emergency egress and ease of breakage for fire fighting. Vinyl prime/replacement windows may be considered the equal of all other windows in these regards. The significant safety variable in window construction is the glazing material and all windows found in this study were made with conventional, breakable glass. Sash and muntin construction in some windows may enhance the ease of emergency exit. This was not considered to be a significant factor.

Code Compliance

The major building codes have no requirements which would relate to window replacement. Local code variations and local code authorities may differ. Therefore, it should be determined from the local building inspector if a building permit is required for window replacement. For example, Chapter 54 of the Uniform Building Code might be interpreted as applying to residential replacement windows. In such cases, windows subject to human impact must meet UBC Standard 54-2.

The Code of Energy Conservation in New Building Construction jointly prepared by BOCA, ICBO, NCSBCS and SBCCI was not considered to be applicable to renovation and replacement. Some individual building inspectors might choose to act otherwise. In such cases, the rather common standard for air infiltration (maximum 0.5 cfm per foot of crack) would be applied.

FHA has minimum property standards relating to windows and ASHRAE 90-75 specifies window performance for energy efficient buildings. Both of these documents apply to new construction.

Product Longevity

The longevity or durability of vinyl windows is a difficult area for purchasers to investigate and evaluate. The exterior durability performance of vinyl siding in America suggests that it is possible to produce light colored vinyl compounds of acceptable durability for use in window frame construction. However, the word "vinyl" does not insure, nor even imply, acceptable durability.

There are no public standards relating to the exterior durability of polyvinyl chloride compounds or extruded shapes. The purchaser must, therefore, rely on the integrity of window suppliers. About the only insurance of acceptable weathering quality available to the purchaser might be to insist on written assurance in the form of a statement such as the following,

"All polyvinyl chloride components used to fabricate --- windows have been extruded from polyvinyl chloride compound expressly formulated for exterior exposure and use. The outdoor color stability and impact strength retention of this compound has been tested for at least two years by --- at ---."

Such a statement is, of course, not applicable to windows which are produced with a weatherable cap stock. Trocal windows are made from PVC but have an acrylic cap stock exposed to the weather on all colors except white. The durability of this cap stock is unknown. "Acrylics" are regarded by many as having superior durability to "vinyls". However, one should not make purchasing decisions based on the reputation of generic plastic names. There can be both poor and good weathering acrylics just as there are different vinyls designed for interior use and for exterior use. A second family of cap stock surfaced vinyl windows is being introduced. These are darker colors, usually in the brown-red

33

family. Such darker colors attain a higher surface
temperature when exposed to the sun. The frames
underlying these cap stock colors should not be produced
from PVC compounds because of the risk of exceeding the
heat distortion temperature of the lineals when the
dark color is exposed to the sun. Chlorinated polyvinyl
chloride (CPVC) is the compound recommended by B.F.
Goodrich to be used as the structural base under dark
cap stocks. CPVC has a higher heat distortion
temperature than PVC.

ASTM D-1784 is a specification which may be applied
to vinyl window frames. While it does not relate to
outdoor durability, the strength and chemical resistance
requirements may be pertinent to product longevity.
Page 29 in this report contains the details on how to
call out the proper classes in ASTM D-1784 for vinyl
window lineals.

National Bureau of Standards Voluntary Product
Standard PS55-72 for Rigid Vinyl Siding contains
references to weatherability which may be applied to
vinyl window extrusions. Paragraph 3.10 contains the
criteria and paragraph 4.10 the test methods.

Another good test for longevity is field
experience. Vinyl windows have been used in America for
less than 20 years. It is suggested that the suppliers
of candidate windows be asked to show and demonstrate
their window units which have been in service at least
five years.

Product Warranty Limitations

Very few window manufacturers referred to any
warrantys or guarantees. A summary of replies appears
below:

Anderson Vinyl Clad Wood   No warranty reference

Weather Shield
Vinyl or Aluminum Clad Wood   No warranty reference

Alcoa
Vinyl and Aluminum Structure   No warranty reference

Polyco Vinyl	Frame and sash guaranteed 20 years. No reference to terms of guarantee.
Evans Vinyl	No warranty reference.
Vinylume Vinyl	Five year warranty, says no visual obstruction on interior surfaces of insulating glass.
	Life of window guarantee against material and workmanship defects. Does not cover glass or screens. Charge for on-site service calls, otherwise remove window, and ship back to factory.
Trocal Vinyl with Exterior Acrylic Cladding	No warranty reference.
State Metal Awning "Finesse"	20 year warranty of freedom from inherent defects. Lists specific examples. Contains disclaimer of "fitness for use".
Mintz Company, Thermo Frame	No warranty reference.
Certain-Teed	"Satisfaction guaranteed", is only reference.

Historic Preservation

Repairs to or replacement of windows in buildings on Army Facilities may require attention to preservation of the historic qualities of the facade and architecture. This factor may add to the cost of replacement windows and may also negate the use of vinyl windows for replacement purposes.

Acoustic Properties

Windows with low air infiltration ratings and tight fitting installation flanges may have beneficial acoustic as well as thermal properties. This could be advantageous in high outside noise areas such as in cities or near aircraft facilities. Nothing has been published on the "as-installed" acoustic qualities of the various replacement window candidates. Research and testing in this area may be desirable.

CRITERIA FOR SELECTION OF VINYL REPLACEMENT WINDOWS

The need for a replacement window should be established before proceeding to the various steps involved in choosing a specific window. Remember that a replacement window is needed only when the existing window cannot be repaired and upgraded with caulking, weatherstripping and a storm window. When it has been determined that a replacement window is required, the following steps will insure selection of an acceptable quality window of suitable cost effectiveness.

1. Obtain competitive bids from at least two sources after first inspecting each candidate window for workmanship and operation.

2. Obtain written certification that each window will comply with the suggested specifications on pages 36 through 43. Request a copy of the pertinent testing report.

3. Calculate the life-cycle cost for each alternative following the procedures detailed in Appendix A. Note that a supplementary analysis tool is contained in Appendix B. This procedure entails the application of a mathematical model to the thermal performance of a window.

4. Compare the results of Item three to the examples in Appendix A. This may show that it would be desirable to obtain additional quotations on thermally improved design aluminum, wood and hybrid windows.

5. Obtain and retain copies of warrantys and guarantees offered by each window manufacturer.

6. A separate energy conservation analysis for each window may be made using the data calculated within Appendix A.

The final selection of a replacement window will most likely be dictated by the life-cycle cost comparison. This comparison includes energy costs over the 20 year study period. The most economical window

alternative might be rejected in cases where the
supplier is unable to supply compliance certification
and authenticated testing data to permit comparisons
with competing windows.

CONCLUSIONS

Vinyl replacement windows offer the potential of
reducing heat loss when they are used in both renovation
and retrofit circumstances.

The dollar savings achieved through energy
conservation may make window replacement an attractive
action to consider.

Selection of the type of window (vinyl, metal,
wood) will be strongly influenced by the installed cost,
and secondly, by the measured air infiltration
performance of each window.

RECOMMENDATIONS

Analyze the energy savings and life-cycle costs
using the methods in Appendix A to determine the
measurable benefits of window replacement and to select
the most beneficial type of window.

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APPENDIX A

LIFE CYCLE COSTING OF WINDOWS

Basis: Forced replacement, select among window types.

Elements of Cost/Saving: initial total installed cost;
annual net energy consumption for heating; periodic
maintenance.

The elements of cost and expense in comparing
window types are as follows:

- removal of existing window

- cost of replacement window

- labor to install replacement window

- maintenance of replacement window if required

- annual energy loss attributable to window

- life of replacement window

Annual Net Energy Consumption

Since we are concerned with comparing one window to
a second or third, we are concerned principally with "U"
value and air infiltration. Obtain these values from
the window manufacturer based upon tests on the actual
style and size of window being considered. If the
manufacturer is unable to provide data, the following
table may be used only for the purpose of making life
cycle cost comparisons. These data must not be used to
represent quality or performance of specific types of
windows.

53

"U" Value of Residential Windows[1]
Single and Double Hung, Casement and Slider

Frame Material	Single Pane	Double Pane
Vinyl	0.75	0.45
Wood	0.80	0.50
Thermal Break Aluminum	1.00	0.55
Aluminum	1.10	0.70

The above data may be used for comparison purposes of windows up to 3 feet to 5 feet with approximately 80 percent glass areas.

Also, use the manufacturers' data on air infiltration. Multiply the figure by the appropriate perimeter and time interval to obtain cubic feet per hour. If no data are available, calculate air infiltration as follows:

- for windows with no factory installed weatherstripping:

$$V = 240 \times L \times W$$

- for windows with factory installed weatherstripping on all mating edges:

$$V = 36 \times L \times W$$

where:

V = air infiltration, cubic feet per hour

L = length of window, feet

W = width of window, feet

_____

[1]ASHRAE Handbook, 1977 Fundamentals; Chapter 22. Various manufacturers' literature.

Calculate the annual heat loss for each window being considered using the following formula:

$$H = 24D \ (AU + 0.018V)$$

H = annual heat loss attributable to window, BTU

D = heating degree days for location being studied. Obtain from weather bureau, airport, or ASHRAE Handbook, 1976 Systems.

A = area of window, square feet

U = thermal conductance of window BTU/sq ft/$^{\circ}$F/hr

V = air infiltration of window, cubic feet per hour

The annual heating cost incurred by each window for one year may now be calculated as follows:

$$E = \frac{H}{r} \times C$$

where:

E = annual heating cost, dollars

H = annual heat loss for each window from previous section

C = cost of fuel used in building, dollars per BTU

r = efficiency of heating system in building expressed as a decimal (70% = 0.70)

The cost of fuel expressed in dollars per BTU may be calculated from conventional billing units as follows:

Electric - divide dollars per kwh by 3413

55

Natural Gas - divide dollars per CCF by 100,000

divide dollars per therm by 100,000

No. 2 Oil - divide dollars per gallon by 140,000

If the efficiency of the heating unit is not known, the following may be used for this comparative calculation.

Electric   - 1.00

Natural Gas   - 0.70

No. 2 Oil   - 0.60

Periodic Maintenance

Periodic maintenance for the various types of windows has been assumed to consist only of painting. Painting frequency or schedule will vary according to building location, compass exposure, shading and paint quality. Use an annual painting frequency based on experience in your area if this is known. If this is not known, use the following data for the comparative calculations. Note that a study period of only 20 years is used based upon the suggestions contained in DoE life-cycle costing guidelines[1].

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[1]Federal Register, Part IV Department of Energy; April 30, 1979.

Type of Window	Paint Once Each
Vinyl (incl. vinyl clad wood)	0 years
Mill finish aluminum	0 years
Anodized aluminum	0 years
Painted Aluminum	10 years
Wood	6 years outside, 7 years inside

The cost to paint a window may be determined from area experience, estimates obtained from painters, or from construction estimating guides[1].

The life of a window should be taken as 20 years for analysis purposes according to DoE guidelines.[2]

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[1]Moselle, Gary ed; National Construction Estimates; Craftsman Book Company

[2]Federal Register; Part IV Department of Energy; April 30, 1979

Example of Life Cycle Costing

Compare three different double hung replacement windows.

1. Vinyl replacement window, double pane, factory weatherstripped.

2. Vinyl clad wood, double pane, factory weatherstripped

3. Unfinished wood, single pane, no factory weatherstripping.

Cost of Removal

The cost of removal usually applicable to all three alternatives is estimated to be $30.00.[1]

Cost of Replacement Window

Use for this example an original rough opening of 3 feet, 2 inches by 5 feet, 8 inches.

- Vinyl Replacement = $332.25   material
    29.50   labor
    $361.75

- Clad wood = $173.50   material
    29.50   labor
    10.50   paint one side
    $213.60

- Unfinished Wood = $ 60.70   material
    29.50   labor
    21.20   paint two sides
    $111.40

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[1]Building Construction Cost Data (1977)

Annual Maintenance

- Vinyl replacement - none

- Clad wood - paint inside of window in 7th and 14th year

- Unfinished wood - paint outside in 6th, 12th, and 18th year; paint inside in 7th and 14th year.

Painting cost is $10.60 per side in 1979.

Annual Energy Loss and Cost

Obtain U and V values from page 53.

-Vinyl U = 0.45

$$V = 36 \times 5 \times 3 = 540$$

- Clad wood U = 0.50

$$V = 36 \times 5 \times 3 = 540$$

- Unfinished wood U = 0.80

$$V = 240 \times 5 \times 3 = 3600$$

Calculate heat loss using equation on page 54. Assume the location is Fort Carson, Colorado. Use 6423 degree days for Colorado Springs.

- Vinyl

H = 24 x 6423 (15 x 0.45 + 0.018 x 540)

= 2,538,883 BTU per year

- Clad wood

H = 24 x 6423 (15 x 0.50 + 0.018 x 540)

= 2,654,497 BTU per year

- Unfinished, single pane wood, no weatherstripping

$$H = 24 \times 6423 \ (15 \times 0.80 + 0.018 \times 3600)$$

$$= 11,838,873 \text{ BTU per year}$$

Now, using the equation on page 54, calculate the annual energy cost attributable to each window assuming a gas furnace of 70 percent efficiency and a natural gas cost of $3.67 per 1,000,000 BTU.[1]

- Vinyl

$$E = \frac{2,538,883 \times \$3.67}{0.70 \times 1,000,000} = \$13.281/\text{year}$$

- Clad Wood

$$E = \frac{2,654,497 \times \$3.67}{0.70 \times 1,000,000} = \$13.921/\text{year}$$

- Unfinished wood

$$E = \frac{11,838,873 \times \$3,67}{0.70 \times 1,000,000} = \$62.071/\text{year}$$

It is important to note that these annual energy cost estimates are useful only for comparative analysis. These costs do not represent actual heating costs attributable to a window because a number of factors such as wall orientation and interior shades will significantly influence the energy performance of a window.

[1]Federal Register, June 1979

Summary of Input

	Vinyl Double Glass Weatherstrip	Vinyl Clad Wood Double Glass Weatherstrip	Wood Single Glass No Weatherstrip
Purchase cost plus removal and installation	$391.75	$243.80	$141.40
Annual Energy Cost	$ 13.28	$ 13.92	$ 62.07
Painting cost $10.60 per side in years	None	7,14	6,7,12,14,18

Life Cycle Cost Analysis

		Vinyl	Vinyl Clad Wood	Wood
A.	Purchase Cost + all labor	$391.75	$243.80	$141.40
B.	Annual Energy Cost	13.28	13.92	62.07
C.	Multiply by Present Worth Factor for 20 Years, 10 percent	8.966	3.966	8.966
D.	Life Cycle Energy Cost (B x C)	119.07	124.81	556.52
E.	Painting Cost X Appropriate Present Worth Factor (Yr)	None	(7)10.60 x 0.513 (14)10.60 x 0.263	(6)10.60 x 0.565 (7)10.60 x 0.513 (12)10.60 x 0.319 (14)10.60 x 0.263 (18)10.60 x 0.180
F.	Life Cycle Painting Cost	None	8.22	19.50
G.	Total Life Cycle Cost (A + D + F)	$510.82	$376.82	$717.42

The vinyl clad wood window of improved thermal design was the clear choice in this example. The reader is cautioned not to generalize based upon this one example. Each circumstance should be calculated using actual costs for the products and services in effect.

Basis: Renovation. An existing old wood window with single pane glass and no factory weatherstripping may be replaced with an energy efficient window. Data from the previous example may be used to illustrate this case. The annual energy cost and maintenance may be used for the single pane wood window in good condition. Removal and replacement costs for this window are now ignored since this window represents an existing window.

Life cycle cost analysis proceeds as follows:

		Vinyl	Vinyl Clad Wood
A.	Purchase Cost + all labor	$391.75	$243.80
B.	Reduced Annual Energy Cost Versus Wood	(48.79)	(48.15)
C.	Multiply by Present Worth Factor for 20 years, 10 Percent	8.966	8.966
D.	Life Cycle Energy Savings	(437.45)	(431.71)
E.	Reduced Life Cycle Painting Cost Versus Wood	(19.50)	(11.28)
F.	Total Life Cycle Cost (Savings) (A + D + E)	(65.20)	(199.19)

Both the vinyl and vinyl clad wood windows offer a net savings over 20 years. An alternative not investigated was storm windows over the existing window. This example may be worth calculating whenever a retrofit circumstance is being considered.

APPENDIX B
MATHEMATICAL MODEL FOR
HEAT LOSS THROUGH WINDOW FRAMES

To approximate the heat loss through a window frame, several dimensions of the frame must be known along with the conductivity of the frame material. Next, the temperatures of the frame surface must be determined inside and out. These temperatures will depend on the air temperature inside and outside, and the frame dimensions and conductivity.

An average window and frame:
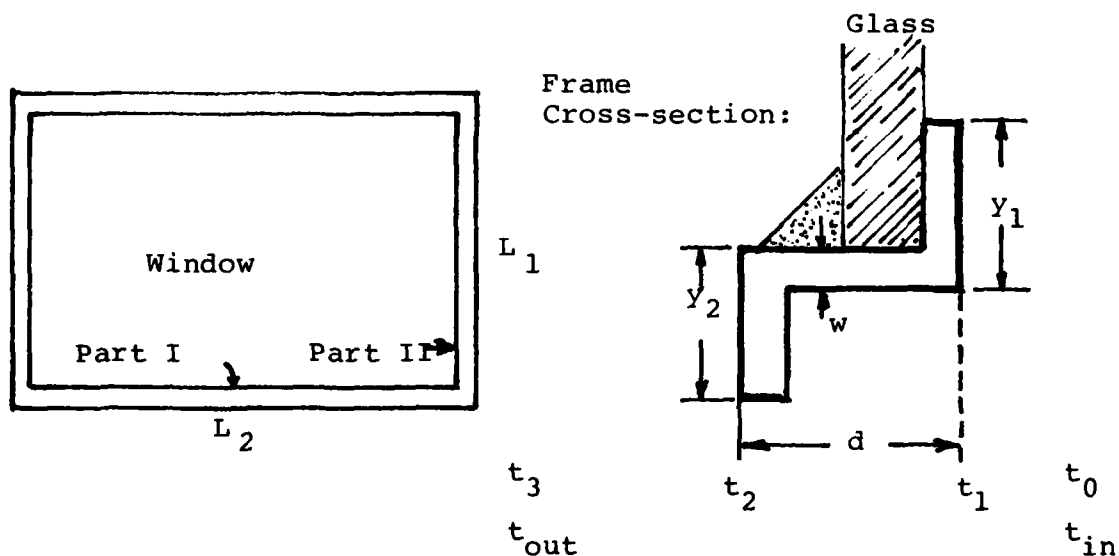
Making a resistance analog of the frame cross section:
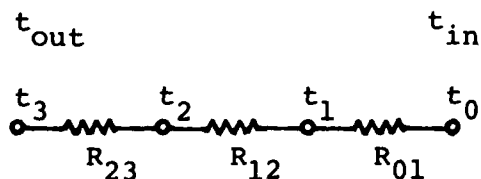
The heat flow through each of these resistances must be equal.

$$q_{01} = q_{12} = q_{23}$$

$$q \simeq CA\Delta T = \frac{A}{R}\Delta T = KA\frac{\Delta T}{\Delta X}$$

So,

$$\frac{A_{01}}{R_{01}}(t_0 - t_1) = \frac{A_{12}}{R_{12}}(t_1 - t_2); \quad \text{let } \frac{A_{01}}{R_{01}} = Z_{01}, \text{ etc.}$$

Then,

$$t_1 = \frac{t_0 \frac{Z_{01}}{Z_{12}} + t_2}{\frac{Z_{01}}{Z_{12}} + 1} \quad \text{and} \quad t_2 = \frac{t_3 \frac{Z_{23}}{Z_{12}} + t_1}{\frac{Z_{23}}{Z_{12}} + 1}$$

now, the free convection coefficients (h) must be calculated.

$$h = \frac{N_{NU} \, k_{air}}{l} \; ; \quad \text{where l is the characteristic vertical length,}$$

$$N_{NU} = C (N_{GR} N_{PR})^m = C(N_{RA})^m$$

where,

laminar flow: $C = 0.59$, $m = \frac{1}{4}$ for $10^4 < N_{RA} < 10^9$

turbulent flow: $C = 0.129$, $m = 1/3$ for $10^9 < N_{RA} < 10^{12}$

Calculate the Rayleigh numbers (N_{RA}) for an example window frame to determine laminar or turbulent flow.

Example:

Assume $T_{out} = 30^{\circ}F$, $T_{in} = 70^{\circ}F$, and $T_{frame} \simeq 50^{\circ}F$

64

Then,

	Inside	Outside
T_m Mean Temperature	$60^{\circ}F$	$40^{\circ}F$
ρ Average Density	0.07633 pcf	0.07938
C_p Specific Heat	0.2404 Btu/lb$^{\circ}$F	0.2404
k Air Conductivity	0.01466 BTU/hr·ft·$^{\circ}$F	0.01416
μ Dynamic Viscosity	0.04339 lb/ft·hr	0.04208

Also,

L_c = crack length; perimeter length of frame = $2(l_1 + l_2)$

l = characteristic vertical length

g = gravitational acceleration = 4.173×10^8 ft/hr^2

β = coefficient of expansion $\simeq$ (T absolute)$^{-1}$ of air at ∞.

$t = |t_{surface} - t_{air}|$

Now,

$$N_{RA} = N_{GR}\, N_{PR} = \frac{l^3 \rho^2 g \beta \Delta t}{\mu^2}\; \frac{\mu C_p}{k} = \frac{\rho^2 g \beta C_p}{\mu k}\,(l^3 \Delta t)$$

Let,

$$y_1 = y_2 = 0.083 \text{ ft (1 inch)}$$

$$l_1 = 4 \text{ ft}$$
$$l_2 = 5 \text{ ft}$$
$$L_c = 18 \text{ ft}$$

$$d = 0.125 \text{ ft (1.5 inch)}$$
$$w = 0.0104 \text{ ft (1/8 inch)}$$

Outside:

Part I.

$$N_{RA} = \frac{(0.07938)^2\,(4.173 \times 10^8)\,(460 + 30)^{-1}\,(0.2404)}{(0.04208)\,(0.01416)}\,\{l^3\, \Delta t\}$$

$$= 2.165 \times 10^6\,\{(4)^3\,(20)\} = 2.77 \times 10^9$$

This is turbulent flow.

Part II

$$N_{RA} = 2.165 \times 10^6 \; \underline{/}(.083)^3 20\underline{/} = 2.476 \times 10^4, \text{ laminar flow}$$

<u>Inside:</u>

Part I

$$N_{RA} = \frac{(.07633)^2 (4.173 \times 10^8)(460 + 70)^{-1}(.2404)}{(.04339)(.01466)} \; \underline{/}l^3 \Delta t\underline{/}$$

$$= 1.734 \times 10^6 \; \underline{/}(4)^3 \; 20\underline{/} = 2.219 \times 10^9, \text{ turbulent flow}$$

Part II

$$N_{RA} = 1.734 \times 10^6 \; \underline{/}(.083)^3 \; 20\underline{/} = 1.983 \times 10^4, \text{ laminar flow}$$

Now, calculate the free convection coefficients,

$$h = \frac{K_{air}}{l} N_{NU} = \frac{K_{air}}{l} C (N_{RA})^m$$

<u>Laminar:</u>

inside,

$$h = \frac{K_{air}}{l} (.59) N_{RA}^{\frac{1}{4}} = K_{air} (.59)(1.734 \times 10^6)^{\frac{1}{4}} l^{-1}(l^3 \Delta t)^{\frac{1}{4}}$$

$$= (.01466)(.59)(1.734 \times 10^6)^{\frac{1}{4}} (\frac{\Delta t}{l})^{\frac{1}{4}} = .314 \; (\frac{\Delta t}{l})^{\frac{1}{4}}$$

outside,

$$h = (.01416)(.59)(2.165 \times 10^6)^{\frac{1}{4}} (\frac{\Delta t}{l})^{\frac{1}{4}} = .320 \; (\frac{\Delta t}{l})^{\frac{1}{4}}$$

<u>Turbulent:</u>

inside,

$$h = \frac{K_{air}}{l} (.129) N_{RA}^{1/3} = (.01466)(.129)(1.734 \times 10^6)^{1/3}$$

$$(\frac{\Delta t}{l})^{1/3} = .227 \; (\frac{\Delta t}{l})^{1/3}$$

66

outside,

$$h = (.01416) \ (.129) \ (2.165 \times 10^6)^{1/3} \ (\tfrac{\Delta t}{l})^{1/3} = .236 \ (\tfrac{\Delta t}{l})^{1/3}$$

Therefore a good approximation to h for all calculations is,

laminar – $\quad\quad\quad h \simeq .32 \ (\tfrac{\Delta t}{l})^{\frac{1}{4}}$

turbulent – $\quad\quad\quad h \simeq .23 \ (\tfrac{\Delta t}{l})^{1/3}$

now, use these to calculate the required terms. Considering each of the four frame members.

$$z_{01} = \{A_{01}\} \ h_{01} = 2\{y_1 l_1\} \ (.23) \left[\frac{t_0 - t_1}{l_1}\right]^{1/3} + 2\{y_1 l_2\} \ (.32) \left[\frac{t_0 - t_1}{y_1}\right]^{1/4}$$

$$z_{12} = \frac{w \ L_c \ k_{frame}}{d} \ ; \quad\quad w = \text{total width of all horizontal members.}$$

$$z_{23} = \{A_{23}\} \ h_{23} = 2 \ \{y_2 \ l_1\} \ (0.23) \left(\frac{t_2 - t_3}{l_1}\right)^{1/3} + 2 \ \{y_2 l_2\}(0.32)\left(\frac{t_2 - t_3}{y_2}\right)^{1/4}$$

Since the convection terms depend on temperature, t_1 and t_2 must be solved for by an iterative method. First calculate t_1, then use this to find t_2, and use this new t_2 to find t_1, etc. This process should continue until t_1 and t_2 no longer change significantly.

AREAS:

$$A_{01} = y_1 L_c$$

$$A_{12} = w L_c$$

$$A_{23} = y_2 L_c$$

Thermal Conductivities –

  Aluminum $\simeq$ 95 Btu/hr. ft.$^\circ$F

  Steel $\simeq$ 30 Btu/hr. ft.$^\circ$F

  Vinyl $\simeq$ 0.12 Btu/hr. ft.$^\circ$F

  Wood $\simeq$ 0.075 Btu/hr. ft.$^\circ$F

  Air $\simeq$ 0.015 Btu/hr. ft.$^\circ$F

Let t_3 or t out equal the average temperature during the heating season and n be the number of days in the heating season.

Then

$$q \text{ lost/year} = 24 \ nK_{frame} \ \frac{A}{d} \ \Delta T \ ; \text{ where } \Delta T = t_1 - t_2$$

$$\frac{z_{01}}{z_{12}} = \frac{2y_1 d}{wK_{frame}} \left[.23 \left(\frac{t_0 - t_1}{l_1} \right)^{1/3} + .32 \left(\frac{t_0 - t_1}{y_1} \right)^{1/4} \right]$$

$$\frac{z_{23}}{z_{12}} = \frac{2y_2 d}{K_{frame}} \left[.23 \left(\frac{t_0 - t_1}{l_1} \right)^{1/3} + .32 \left(\frac{t_2 - t_3}{y_2} \right)^{1/4} \right]$$

Using the previous example values,

1) Aluminum frame

$$\frac{z_{01}}{z_{12}} = 0.0210 \left(0.63 \ (t_0 - t_1)^{1/3} + 1.863 \ (t_0 - t_1)^{1/4} \right)$$

$$\frac{z_{23}}{z_{12}} = 0.0210 \left(0.63 \ (t_2 - t_3)^{1/3} + 1.863 \ (t_2 - t_3)^{1/4} \right)$$

The constants are the same in this case because,

$$y_1 = y_2$$

After iteration on the temperatures:

$$t_3 \qquad t_2 \qquad t_1 \qquad t_o$$

$$30^\circ F \quad 48.90^\circ F \quad 51.11^\circ F \quad 70^\circ F$$

Then, assuming there are 200 days in the heating season with the average outside temperature = $30^\circ F$.

$$q \text{ lost/year} = 24(200)(95) \frac{0.0104 \ (18)}{0.125} (51.11-48.90) =$$

$$1.508 \times 10^6 \ \frac{BTU}{year}$$

2) **Steel frame** (assuming same frame dimensions, etc.)

$$\frac{z_{01}}{z_{12}} = 0.06651 \left[0.63 \ (t_o-t_1)^{1/3} + 1.863 \ (t_o-t_1)^{1/4} \right]$$

$$\frac{z_{23}}{z_{12}} = 0.06651 \left[0.63 \ (t_2-t_3)^{1/3} + 1.863 \ (t_2-t_3)^{1/4} \right]$$

After iteration:

$$t_3 \qquad t_2 \qquad t_1 \qquad t_o$$
$$30^\circ F \quad 46.96^\circ F \quad 53.05^\circ F \quad 70^\circ F$$

Then,

$$q \text{ lost/year} = 7188 \ (30) \ (53.05 - 46.96) = 1.313 \times 10^6 \ \frac{BTU}{year}$$

3) **Vinyl frame** (again, same dimensions, etc.)

$$\frac{z_{01}}{z_{12}} = 16.63 \left[0.63 \ (t_o-t_1)^{1/3} + 1.863 \ (t_o-t_1)^{1/4} \right]$$

$$\frac{z_{23}}{z_{12}} = 16.63 \left[0.63 \ (t_2-t_3)^{1/3} + 1.863 \ (t_2-t_3)^{1/4} \right]$$

After iteration:

t_3	t_2	t_1	t_o
$30^\circ F$	$30.94^\circ F$	$69.06^\circ F$	$70^\circ F$

Then;

$$q \text{ lost/year} = 7188(0.12)(69.06-30.94) = 3.289 \times 10^4 \frac{BTU}{year}$$

Of course, if each window dimension was different, most of the calculation would have to be repeated. However, for this example, the dimensions were assumed the same.

Radiation

Worst possible case: aluminum frame with high emittance (0.8) and a black background (1.0) outside.

$$q \text{ lost/year} \quad \frac{24n\ y_2 L_c\ \ \sigma\ \{(t_3+460)^4-(t_2+460)^4\}}{\frac{1}{\epsilon_{background}} + \frac{1}{\epsilon_{frame}} - 1}$$

$$\simeq \frac{24(200)(0.0104)(18)(1.7143 \times 10^{-9})\ \{(51.11+460)^4 - (48.9+460)^4\}}{\frac{1}{1.0} + \frac{1}{0.8} - 1}$$

$\simeq 1.45 \times 10^3 \frac{BTU}{year}$ This is 0.1 percent of the heat lost by conduction and convection.

Radiation in the other cases would be even less and can therefore be neglected.

To determine the time to recover an investment in vinyl windows:

Number of years to recoup investment $= n = \dfrac{\log\{\frac{P(a-1)}{s} + a\}}{\log a}$

where $a = \dfrac{(1+f)}{(1+i)}$

and,

S = Operating cost savings in first year

C = Cost of heating per therm (10^5BTU)

f = Annual percentage rate of fuel price increase

i = percentage interest rate on alternative investment

P = added cost of windows

$$S = \{q \text{ lost/year}^{(\text{old windows})} - q \text{ lost/year}^{(\text{vinyl windows})}\}\frac{C}{10^5}$$

Suppose:

C ≃ \$0.40, f ≃ 15%, i ≃ 13%, P ≃ \$332

Then,

a = 1.14, $S = 4 \times 10^{-6} \Delta q$

1) Replace aluminum windows with vinyl windows:

$S = 4 \times 10^{-6} (1.508 \times 10^6 - 3.298 \times 10^4) = 5.90$

$$n = \frac{\log \{\frac{332(1.14 - 1)}{5.90} + 1.14\}}{\log(1.14)} \approx 16.8 \text{ years}$$

2) Replace steel windows with vinyl windows

$S = 4 \times 10^{-6} (1.313 \times 10^6 - 3.298 \times 10^4) = 5.12$

$$n = \frac{\log \{\frac{332(1.14 - 1)}{5.12} + 1.14\}}{\log(1.14)} \approx 17.7 \text{ years}$$

These estimates do not include effects of air infiltration or wind. If there would be a significant number of windy days then the payback period would be shorter.

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